

(19)



Eur päisches Patentamt

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Office européen des brevets



(11)

EP 0 712 014 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

15.05.1996 Bulletin 1996/20

(51) Int. Cl.⁶: G02B 6/26

(21) Application number: 95109342.6

(22) Date of filing: 16.06.1995

(84) Designated Contracting States:
DE FR GB

(30) Priority: 11.11.1994 JP 303040/94

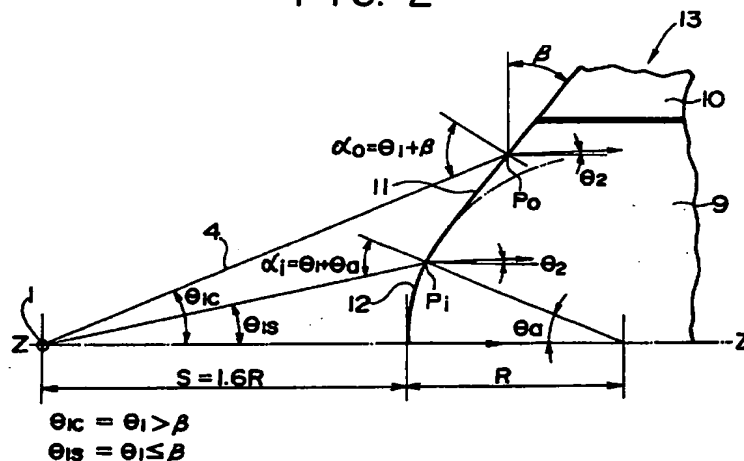
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(54) Optical fiber light coupling interface and method for making same

(57) An optical fiber interface to couple a light source (1) to an optical fiber (13) and also a method of fabricating the optical fiber interface are disclosed. The optical fiber interface includes an improved optical fiber end-face which is used to couple the light power radiated from the light source to the single-mode optical fiber at high light coupling efficiency without the use of intermediate lenses. The optical fiber interface consists of a sphere (12) and part of conical surface (11) tangent to the sphere (12). In the sphere (12) the light input end-face structure of the optical fiber core (9) lies on the optical

axis (Z-Z) of the optical fiber (13). The method of fabricating the optical fiber end-face in the optical fiber interface has following processes. In first process the optical fiber end-face is inserted into the ferrule and fastened there and conical surface (11) is formed by using a conventional cylindrical grinder. And in second process the conical surface (11) is pushed toward an elastic material disk where to an abrasive material is attached so that the sphere (12) is formed by polishing the optical fiber end.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates to an optical fiber light coupling interface between a light source, such as laser diode or LED and the end of an optical fiber and the method for making same.

2. PRIOR ART

A number of proposals have been disclosed on the optical fiber interface wherein a graded index lens (i.e., Selfoc lens) and/or a convex lens is inserted into the gap between a light source and an optical fiber. This type of optical fiber interface has such problems that the optical axes of the respective elements can not easily be aligned, and that the inclination of the optical axis of a certain element, even if the inclination is a minor one, it drastically increases the light coupling loss. These problems created a number of studies on the direct coupling of light power from a light source to the optical fiber. For instance, a system of the direct light coupling has appeared in a paper entitled "A new scheme of coupling from LD to SMF utilizing a beam-expanding fiber with a spherical end", Shirai, et.al., presented at the 1990 Spring National Conference of the Institute of Electronics, Information and Communication Engineers.

A basic configuration of a light coupling device to couple the light source to the single-mode optical fiber, wherein the light source, i.e., a laser diode (LD) or a light emitting diode (LED), is directly coupled to the optical fiber end-face without the use of any optical lens systems, will be described hereafter.

Figure 6 shows an example of the above mentioned light coupling device to couple the light source to the single-mode optical fiber, wherein the light power input end-face is perpendicular to the optical axis thereof. A light power 4 which radiates from a light source 1, i.e., a laser diode (LD), enters into an optical fiber end-face consisting of an optical fiber core 2 and an optical fiber clad 3.

The light power 4 which is radiated from the laser diode (LD), if the laser diode is used as a light source, is distributed around the optical axis thereof in accordance with the Gaussian function in terms of radiation angle θ_1 of the light power 4 and the laser beam is coherent that will cause diffraction. The radiation pattern is thus elliptical in shape. The elliptically shaped light beam has a major axis XX' which measures 40 to 60 degrees from the light source and a minor axis YY' which measures 20 to 30 degrees from the light source.

Transmission angle θ_2 whereat the light power can be transmitted within optical fiber core 2 should be equal to or less than threshold angle θ_c . That is:

$$\theta_2 \leq \theta_c = \cos^{-1} (n_2 / n_1)$$

where n_1 is the refractive index of the optical fiber core, and n_2 is the refractive index of the optical fiber clad. If we assume $n_1 = 1.47$ and $n_2 = 1.467$ for a single-mode optical fiber, then $\theta_c = 3.624$ degrees can be obtained.

If transmission angle θ_2 satisfies expression $\theta_2 \leq \theta_c$ for the transmission of the light power within the optical fiber core 2, radiation angle θ_1 should be equal to or less than numerical aperture NA of the optical fiber core. That is:

$$\theta_1 \leq NA = n_0 \sin \theta_c$$

where n_0 is the refractive index of air ($n_0 = 1$).

The numerical aperture NA of the optical fiber core for a threshold angle θ_c of 3.624 degrees is equal to 5.33 degrees ($\theta_1 \leq 5.33^\circ$). If the average radiation angle θ_1 for all light power flux 4 is 25 degrees, and the effective incident angle θ_1 to the end-face of optical fiber core 2 is limited to 5.33 degrees or less ($\theta_1 \leq 5.33^\circ$), the percentage of the light power transmitted through the optical fiber core for a single-mode optical fiber to that which is radiated from the light source is approximately 20% if all other losses are disregarded.

If the light power entering on the optical fiber core at an incident angle θ_1 of greater than 5.33 degrees, it enters into the optical fiber clad 3, which will be lost from the optical fiber core during the transmission through the optical fiber. This is the reason that the light coupling loss occurs. As shown in Figure 6, transmission angle θ_2 increases with radiation angle θ_1 and finally becomes greater than threshold angle θ_c causing light coupling loss. In order to increase the light coupling efficiency measured from the light source to the optical fiber core, transmission angle θ_2 should be equal to or less than threshold angle θ_c for all radiation angles θ_1 . A direct light coupling system of this type has thus not been used in most light coupling.

As described heretofore, the light coupling efficiency at the interface between the light source and the optical fiber in the direct light coupling system is inherently low. Many experiments have been done to improve the light coupling efficiency in the direct light coupling system. Among those, a typical example is shown in Figure 5.

An optical fiber consisting of an optical fiber core 5 and an optical fiber clad 6 is fused, drawn, and cut to form tapered section 7 whose diameter is gradually decreased toward the end-face thereof so that mode radius ω of the optical fiber core 5 is extended toward the end-face thereof. A hemispherically shaped microlens 8 is formed at the end of the optical fiber so as to improve the light coupling efficiency. For further information, see IEEE Journal of Lightwave Technology, Vol. 11, No. 2, pp. 252-257 (February 1993).

If the ratio of distance S between the light source and the optical fiber end-face to radius R of microlens 8 is properly defined in the aforementioned example, transmission angle θ_2 can be equal to or less than threshold angle θ_c in a wide range of radiation angle θ_1 . In this case, incident angle α is equal to $(\theta_1 + \theta_a)$ where θ_a will be described hereafter. If incident angle α is greater than Brewster's angle θ_B , the reflection of the light power at the optical fiber end-face increases and the transmitted light power decreases.

Brewster's angle θ_B is expressed as follows:

$$\theta_B = \tan^{-1} n_2$$

θ_B is 55.77 degrees for $n_1 = 1.47$. As radiation angle θ_1 increases, angle θ_a between point P₁ on the hemisphere and optical axis ZZ' rapidly increases. That is; incident angle α becomes equal to Brewster's angle θ_B for a small amount of increase in radiation angle θ_1 . According to calculations, incident angle α is nearly equal to θ_B ($\alpha \approx \theta_B$) at radiation angle (θ_1) of approximately 18 degrees for $S = 1.6R$. Transmission angle θ_2 is nearly equal to 3.6 degrees ($\theta_2 \approx 3.6^\circ$) at a radiation angle of approximately 18 degrees, which is nearly equal to optical fiber threshold angle θ_c . Note that this fact is important.

The light power radiated at a radiation angle of greater than 18 degrees ($\theta_1 > 18^\circ$) is not propagated along the optical fiber core causing the light power loss. According to IEEE Journal of Lightwave Technology, Vol. 11, No. 2, pp. 252-257 (February 1993), a paraboloidal surface of an optical fiber end-face not shown, which is formed by laser welding machine, is proposed so that transmission angle θ_2 is set to be nearly equal to 0 degree ($\theta_2 \approx 0^\circ$) regardless of radiation angle θ_1 . The optical property change due to fusing of the optical fiber end-face, however, is unknown in this proposal, which leaves improvement in processing machines and techniques.

A paper entitled "A new scheme of coupling from LD to SMF utilizing a beam-expanding fiber with a spherical end", by Shirai et. al., presented at the 1990 Spring National Conference of the Institute of Electronics, Information and Communication Engineers, has appeared. This paper describing an optical fiber having a spherical end-face points out that the optical loss due to inclination of the optical axis for the spherical end-face is greater than that for the standard single-mode optical fiber end-face. See Figure 6 for details.

As described heretofore, a light coupling lens wherein an optical fiber end-face structure such as that which is disclosed in this specification is formed at the front end of the light coupling lens. This lens has been disclosed in Japanese Patent Application KOKAI 1987-81615 in 1987. The optical axis alignment in these disclosures is difficult since the inclination of the optical axis greatly affects the light coupling loss, which has been described heretofore.

As described heretofore, effective light coupling from the light source directly to the optical fiber is difficult; however, direct light coupling from the light source to the optical fiber is attractive for the designer to construct a light coupling device of simple structure.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an optical fiber interface having an improved end-face structure, which couples the light power from the light source to the optical fiber at a high light coupling efficiency, and the other object of the present invention is to provide the method of fabrication thereof.

In order to accomplish the object of the present invention, an optical fiber interface to couple a light source to an optical fiber, which is built in accordance with the present invention, provides an incident end-face structure of the optical fiber core, consisting of a sphere whose center lies on the optical axis of the optical fiber, and part of a conical surface tangent to the sphere.

In the optical fiber interface to couple the light source to the optical fiber, radius R of the sphere can be built smaller than mode radius ω of the optical fiber and inclination angle β of the part of a conical surface can be equal to or greater than 25 degrees ($\beta \geq 25^\circ$) with respect to the plane perpendicular to the optical axis of the optical fiber.

In the optical fiber interface to couple the light source to the optical fiber, distance S between the light source and the optical fiber end-face can be equal to or greater than radius R.

In the optical fiber interface to couple the light source to the optical fiber, following expression (1) is valid for the light beam incident on the sphere from the light source and following expression (2) is valid for the light beam input to the part of a conical surface from the light source.

$$\theta_c \geq \theta_2 = \sin^{-1} \{ \sin(\theta_1 + \theta_a) \} / n_1 - \theta_a \quad (1)$$

$$\theta_c \approx \theta_2 = \sin^{-1} \{ \sin(\theta_1 + \beta) / n_1 \} - \beta \quad (2)$$

where

θ_c : threshold angle of the optical fiber core.

θ_2 : transmission angle of the light beam entered into the optical fiber core.

θ_1 : radiation angle of the light beam from the light source.

n_1 : refractive index of the optical fiber core.

θ_a : angle between the optical axis of the optical fiber and the normal line leading from the incident point on the sphere to the center of the sphere when the light beam is radiated from the light source at radiation angle θ_1 .

According to the invention, a method of fabricating an optical fiber interface to couple a light source to an optical fiber comprising the steps of:

inserting an optical fiber into a ferrule and fastening the optical fiber to the ferrule;

forming a conical surface at the end surface of the optical fiber by using a cylindrical grinder; and

forming a spherical surface at the end of the conical surface of the optical fiber by using a spherical grinder.

In the method of fabricating the optical fiber interface to couple the light source to the optical fiber, the spherical grinder to polish the optical fiber end-face is a polishing device to polish the optical fiber end-face with an abrasive material on a surface of an elastic material disk, when the elastic material disk whose surface is covered with the abrasive material, revolves around its revolving axis while the revolving axis rotating with respect to the optical fiber end-face.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic cross-sectional view of an optical fiber end-face used as an optical fiber interface to couple a light source to the optical fiber, which is built in accordance with the present invention.

Figure 2 shows optical paths of incident light beam in the optical fiber end-face described in Figure 1.

Figure 3 shows transmission angles θ_2 in terms of radiation angles θ_1 for the optical fiber end-face built in accordance with the present invention (plot A), for that which constitutes a sphere (plot B), and for that which constitutes a plane perpendicular to the optical axis thereof (plot C), respectively.

Figure 4 shows light coupling efficiencies η_A , η_B and η_C for plots A, B and C of Figure 3, when a laser diode is used as a light source, where any additional light losses other than those described herein are disregarded.

Figure 5 shows a structure and an optical path of an optical fiber end-face which constitutes a sphere in the prior art (refer to plot B of Figure 3).

Figure 6 shows a single-mode optical fiber end-face which constitutes a plane perpendicular to the optical axis thereof, which belongs to the techniques in the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described in detail referring to the drawings.

Figure 1 shows a schematic cross-sectional view of a single-mode optical fiber end-face structure to couple light power from a light source to an optical fiber, showing an embodiment of an optical fiber interface to couple the light source to the optical fiber, which is built in accordance with the present invention.

An end-face structure of a core 9 and a clad 10 of a single mode optical fiber 13 consists of a sphere with radius R whose center lies on the optical axis (z-z) of the optical fiber, and a conical surface 11 whose central line lies on the optical axis thereof, and is tangent to the sphere. Point Q in Figure 1 indicates the vertex of the conical surface which lies on the Z coordinate.

An inclination angle β of the conical surface with respect to the plane which is perpendicular to the optical axis is 35 degrees ($\beta = 35^\circ$) in this embodiment, and the radius R of the sphere 12 is $5\mu\text{m}$ ($R = 5\mu\text{m}$).

The fabrication method of the single-mode optical fiber end-face to couple the light source to the optical fiber will be described hereinafter. The single-mode optical fiber is inserted into a hole at the center of a cylindrical ferrule (not shown) and fastened there by wax. Thereafter, the end-face of the conical surface 11 is formed by polishing the cylindrical ferrule with a conventional cylindrical grinder (not shown).

After that the conical end-face at the end of the optical fiber is pushed toward an elastic material disk (not shown) of the conventional optical fiber end polishing machine. As the elastic material disk whose surface is covered with an abrasive material revolves around its revolving axis, while the revolving axis rotates with respect to the optical fiber end-face. During these operations, the vertex of conical surface 11, which is formed by using the spherical grinder, is formed into a sphere 12. The conventional optical fiber end polishing machine and polishing method are described in the Japanese Patent Application No. 1994-184060 in 1994. Other grinders specified by U.S.P. 4,831,784 and U.S.P. 4,979,334 can also be used for this purpose.

After the polishing is completed the temperature of the optical fiber and ferrule is elevated to 120°C so that the wax which fastens the optical fiber to the ferrule is melted, and the optical fiber is removed from the hole at the center of the ferrule. The optical fiber end-face is thus completed.

The optical fiber end-face to couple the light source to the optical fiber, which has been fabricated in the manner described heretofore, can be fastened to the aligned V groove provided on the surface of a flat plate so as to use it in practical application.

If the optical fiber end-face to couple the light source to the optical fiber is used together with the ferrule wherein the optical fiber end-face is installed, epoxy resin or soldering can be used in place of the wax so that the optical fiber is permanently fastened to the ferrule.

Figure 2 also shows the relationship between the optical fiber end-face and a light source when the optical fiber end-face to couple the light source to the optical fiber is built in accordance with the present invention.

Assume that angle β of inclination on the surface of the conical surface is 35 degrees ($\beta = 35^\circ$). Distance S between light source 1 and the end-face of optical fiber 13 to couple the light source 1 to optical fiber 13 is determined to be 1.6 R in terms of radius R of sphere 12 at the end-face of an optical fiber 13. That is $S = 1.6R$.

The light power incidence on the surface of sphere 12 from the light source will be discussed hereafter.

Assume that angle θ_a is defined as the angle between the line leading from incident point P_i to the center of the sphere and the optical axis Z-Z. Note that $\theta_a < \beta = 35^\circ$.

The light power incidence on a point on the sphere will be described hereafter.

Incidence angle α_i for the light beam incidence on incident point P_i is given by

$$\alpha_i = \theta_a + \theta_{1s} = \tan^{-1} \{ \sin \theta_a / (2.6 - \cos \theta_a) \} + \theta_a$$

For the case where θ_a is 35 degrees ($\theta_a = 35^\circ$), a radiation angle θ_1 becomes 17.85 degrees ($\theta_{1s} = 17.85^\circ$) and an incident angle α_i becomes 52.85 degrees ($\alpha_i = 52.85^\circ$). The light beam at a radiation angle θ_1 of 17.85 degrees or less ($\theta_{1s} = \theta_1 \leq 17.85^\circ$) can be incident on the surface of the sphere.

The light beam incidence on the conical surface outside the sphere will be discussed hereafter. For the light beam at a radiation angle θ_1 of 17.85 degrees or more ($\theta_{1c} = \theta_1 > 17.85^\circ$), incident angle α_0 at incident point P_0 is calculated by

$$\alpha_0 = \theta_{1c} + \beta = \theta_{1c} + 35$$

This equation means that incident angle α_0 is given by the sum of radiation angle θ_{1c} and angle β of inclination on the conical surface when angle β is equal to 35 degrees.

If compared with the sphere at the optical fiber end-face shown in Figure 5, the light beam at large radiation angle θ_1 than that which is defined in Figure 5 can be input to the optical fiber on condition that $\theta_2 \leq \pm \theta_c$.

Figure 3 shows a series of graphs whereon transmission angle θ_2 is given in terms of radiation angle θ_1 of the optical fiber end-face to couple the light source to the optical fiber in the optical fiber interface.

Plot A indicates transmission angle θ_2 in terms of radiation angle θ_1 for the optical fiber end-face to couple the light source to the optical fiber, which is built in accordance with the present invention.

Plot B indicates transmission angle θ_2 in terms of radiation angle θ_1 for the optical fiber end-face to couple the light source to the optical fiber, which is built using such an optical fiber end-face (which constitutes a ball) as shown in Figure 5.

Plot C indicates transmission angle θ_2 in terms of radiation angle θ_1 for the optical fiber end-face to couple the light source to the optical fiber, which is built using such an optical fiber end-face (which has a flat surface which is perpendicular to the optical axis thereof) as shown in Figure 6.

As shown in Figure 3, the optical fiber end-face of plot A is characterized in that the light beam at the radiation angle (θ_1) of up to 32 degrees can be transmitted through the optical fiber on condition that $\theta_2 \leq \pm \theta_c$. The optical fiber end-face of plot B is characterized in that the light beam at a radiation angle (θ_1) of approximately up to 18 degrees can be transmitted on condition that $\theta_2 \leq \pm \theta_c$. The optical fiber end-face of plot C is characterized in that the light beam at a radiation angle (θ_1) of approximately up to 5.3 degrees can be transmitted on condition that $\theta_2 \leq \pm \theta_c$.

Figure 4 shows light coupling efficiencies η_A , η_B and η_C for plots A, B and C of Figure 3, respectively. In Figure 4, a laser diode is used as a light source and additional light losses are disregarded.

As shown in Figure 4, light coupling efficiency η_A for the optical fiber end-face of plot A is nearly equal to 83% on condition that $\theta_2 \leq \pm \theta_c$. Light coupling efficiency η_B for the optical fiber end-face of plot B is nearly equal to 59% on condition that $\theta_2 \leq \pm \theta_c$. Light coupling efficiency η_C for the optical fiber end-face of plot C is nearly equal to 19% on condition that $\theta_2 \leq \pm \theta_c$.

The light coupling efficiency for the single-mode optical fiber end-face is actually estimated to be approximately 70% due to light beam reflection at the optical fiber end-face and due to alignment errors in optical axes.

Angle β of inclination on the conical surface, radius R of the sphere, and distance S between the light source and the optical fiber end-face are, in the embodiment of the present invention, examples which are measured for the standard

single-mode optical fiber. Depending on the parameters of the optical fiber used, the optimum values which satisfy the following expressions should be selected as the design values.

For the light beam incidence on the spherical portion of the optical fiber,

$$\theta_c \geq \theta_2 = \sin^{-1} \{ \sin (\theta_1 + \theta_a) / n_1 - \theta_a \} \quad (1)$$

For the light beam incidence on the conical portion of the optical fiber,

$$\theta_c \geq \theta_2 = \sin^{-1} \{ \sin (\theta_1 + \beta) / n_1 - \beta \} \quad (2)$$

The optical fiber interface to couple the light source to the optical fiber, which is built in accordance with the present invention, can receive the light power on the surface of the spherical portion of the optical fiber end-face for the light beam radiated from the light source at low radiation angle, and receive the light power on the surface of the conical portion of the optical fiber end-face for the light beam radiated from the light source at high radiation angle. The light beams input from the light source over the wide range of radiation angles can be converted into the light beams at transmission angles within the threshold angle.

The light coupling efficiency to couple the light source to the single-mode optical fiber can thus be improved.

The optical fiber end-face to couple the light source to the optical fiber can easily be fabricated using conventional fabrication facilities and techniques.

The present invention can be applied to any other types of optical fibers other than the standard single-mode optical fibers, i.e., an optical fiber of a dispersion shifted fiber a polarization maintaining fiber or a optical fiber with an extended mode field diameter which is extended to 20 to 40 μm by drawing and fusing the optical fiber, if parameter values are properly selected.

Claims

1. An optical fiber interface to directly input light power from a light source (1) to an optical fiber end-face; wherein the incident end-face structure of the core (9) of said optical fiber (13) consists of a sphere (12) whose center lies on the optical axis (Z-Z) of said optical fiber (13), and part of a conical surface (11) tangent to said sphere (12).

2. The optical fiber interface to couple the light source (1) to the optical fiber (13), as claimed in claim 1; wherein radius R of said sphere (12) is smaller than mode radius ω of said optical fiber (13), and

angle β of the inclination on said part of the conical surface (11) is that which is measured with respect to the plane perpendicular to the optical axis (Z-Z) of said optical fiber (13), and angle β is to be equal to or greater than 25 degrees ($\beta \geq 25^\circ$).

3. The optical fiber interface to couple the light source (1) to the optical fiber (13), as claimed in claim 2; wherein distance S between said light source (1) and the optical fiber end-face is to be equal to or greater than radius R

$$(S \geq R).$$

4. The optical fiber interface to couple the light source (1) to the optical fiber (13), as claimed in claim 2; wherein

equation (1) is valid for the light beam from said light source (1) which is incident on said sphere (12), and equation (2) is valid for the light beam from said light source (1) which is incident on said part of the conical surface (11):

$$\theta_c \geq \theta_2 = \sin^{-1} \{ \sin (\theta_1 + \theta_a) / n_1 - \theta_a \} \quad (1)$$

and

$$\theta_c \geq \theta_2 = \sin^{-1} \{ \sin (\theta_1 + \beta) / n_1 - \beta \} \quad (2)$$

where

θ_c : threshold angle of the optical fiber core (9);

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θ_2 : transmission angle at which the light beam is transmitted in the optical fiber core (9);

θ_1 : radiation angle of the light beam from the light source (1);

n_1 : refractive index of the optical fiber core (9);

and

θ_a : angle between the optical axis (Z-Z) of the optical fiber (13) and the line leading from the incident point (Pi) on the sphere (12), whereon the light beam is incident at radiation angle θ_1 , to the center of the sphere (12).

- 5 5. A method of fabricating an optical fiber interface to couple a light source (1) to an optical fiber (13) comprising the steps of:

10 inserting an optical fiber (13) into a ferrule and fastening said optical fiber to said ferrule;

forming a conical surface (11) at the end surface of said optical fiber (13) by using a cylindrical grinder; and

forming a spherical surface (12) at the end of the conical surface (11) of the optical fiber (13) by using a spherical grinder.

- 15 6. The method of fabricating the optical fiber interface to couple the light source (1) to the optical fiber (13), as claimed in claim 5:

said spherical grinder to polish said optical fiber end-face is a polishing device to polish said optical fiber end-face with an abrasive material on a surface of an elastic material disk, when said elastic material disk whose surface is covered with said abrasive material, revolves around its revolving axis while the revolving axis rotating with respect to said optical fiber end-face.

FIG. 3

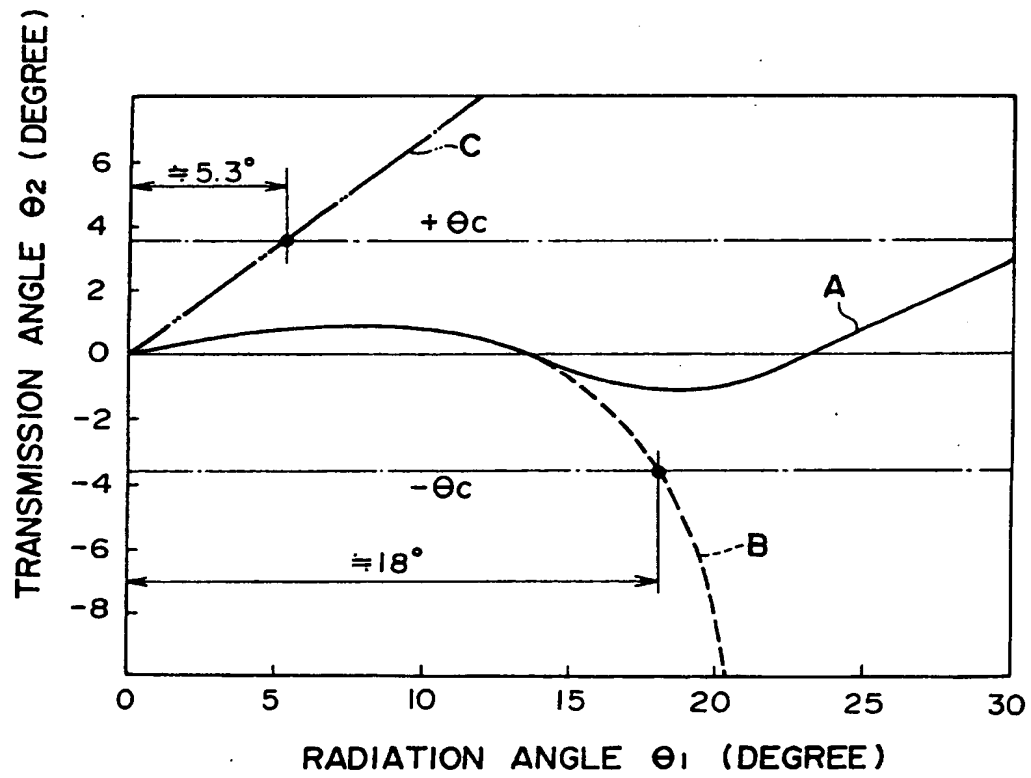


FIG. 4

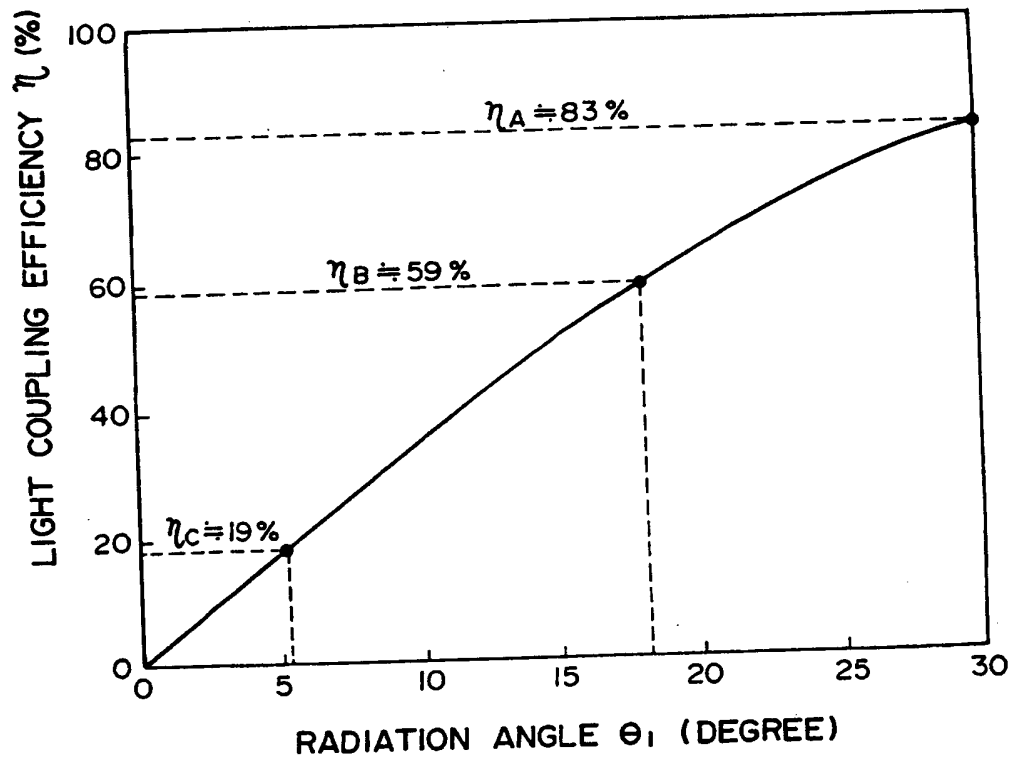


FIG. 5 PRIOR ART

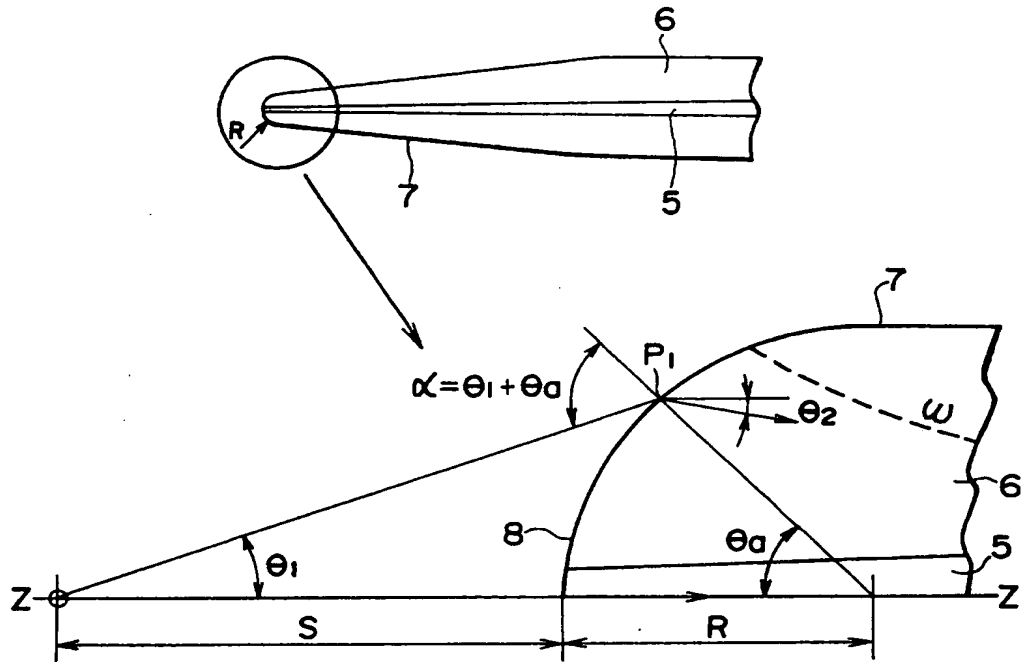
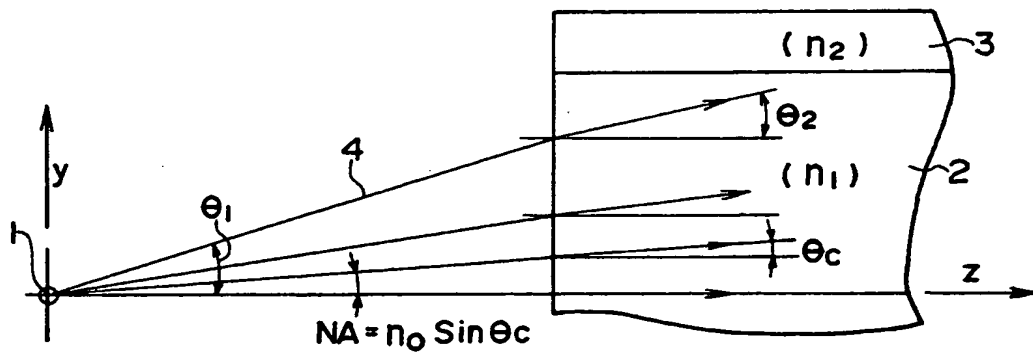


FIG. 6 PRIOR ART



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EUROPEAN SEARCH REPORT

Application Number
EP 95 10 9342

DOCUMENTS CONSIDERED TO BE RELEVANT			Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Category	Citation of document with indication, where appropriate, of relevant passages			
X	PATENT ABSTRACTS OF JAPAN vol. 010 no. 371 (P-526), 11 December 1986 & JP-A-61 165709 (HITACHI LTD) 26 July 1986, * abstract; figure *	1,2	G02B6/26	
Y	IEE PROCEEDINGS J. OPTOELECTRONICS, vol. 141, no. 3, PART J, 1 June 1994 pages 178-184, XP 000438863 JOHN J ET AL 'MATCHING OF SINGLE-MODE FIBRE TO LASER DIODE BY MICROLENSES AT 1.5 UM WAVELENGTH' * abstract * * page 182, right column, last paragraph; figure 9 *	1-3		
Y	APPLIED OPTICS, 1 OCT. 1982, USA, vol. 21, no. 19, ISSN 0003-6935, pages 3470-3474, EISENSTEIN G ET AL 'Chemically etched conical microlenses for coupling single-mode lasers into single-mode fibers' * page 3470, right column, line 23 - line 29 * * figure 1 *	1-3		
X	PATENT ABSTRACTS OF JAPAN vol. 017 no. 290 (P-1549), 3 June 1993 & JP-A-05 019139 (CITIZEN WATCH CO LTD) 29 January 1993, * abstract; figure *	5	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02B	
The present search report has been drawn up for all claims				
Place of search BERLIN		Date of completion of the search 27 February 1996	Examiner Hylla, W	
CATEGORY OF CITED DOCUMENTS			I : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document				

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EUROPEAN SEARCH REPORT

Application Number
EP 95 10 9342

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	SIEMENS FORSCHUNGS- UND ENTWICKLUNGSBERICHTE, 1984, WEST GERMANY, vol. 13, no. 6, ISSN 0370-9736, pages 284-288, KEIL R ET AL 'Coupling between semiconductor laser diodes and single-mode optical fibers' *page 287, item 3, paragraph 3; Figure 4* *Table 2*	1-3	
A,D	US-A-4 831 784 (TAKAHASHI MITSUO) 23 May 1989 * abstract; figure 1 *	6	
A,D	JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. 11, no. 2, 1 February 1993 pages 252-257, XP 000372722 EDWARDS C A ET AL 'IDEAL MICROLENSES FOR LASER TO FIBER COUPLING' * abstract; figures 5,6 *	1-3	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 27 February 1996	Examiner Hylla, W
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

EPO FORM 150 012 (P04C01)

DOCKET NO: AMB-02131-02

SERIAL NO: 10/728,384

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